Thirteen Years of Monitoring the Hemlock Woolly Adelgid In New Jersey Forests[1]

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Abstract

The hemlock woolly adelgid (HWA) is negatively impacting hemlock stands in New Jersey and mortality in the most heavily infested stands is increasing and is above 90% in some plots. The longer it has been since the stand was heavily infested and the more times that a stand has been heavily infested, the greater the mortality. Tree mortality shows up 5-6 years after a stand has been heavily infested the first time, the HWA population crashes and the remaining trees recover. The HWA increases its population again, and the mortality substantially increases. It has taken about ten to twelve years from the initial heavy infestation to see mortality level of over 90% in certain stands. Other factors are involved such as site conditions and water supply, but the one factor that is consistent across the stands where the mortality is the greatest is a heavy population of HWA. The USFS crown rating of foliage transparency increased in the monitored stands as the HWA population increased. At a threshold of 60% crown transparency, the tree mortality in the stands increased significantly. Crown transparency would be a useful tool for forest managers because of its ease of use. There are 15-20 remaining moderately impacted hemlock stands in New Jersey and they are primarily in the northwestern corner of the state.

Introduction

This report is the result of the Study Plot monitoring program partially funded by the United States Department of Agriculture - Forest Service and by the New Jersey Department of Environmental Protection - Division of Parks and Forestry. The objective of this work is to show the impact of the hemlock woolly adelgid (HWA) and associated factors in natural hemlock stands over an extended period. Data collected include stand mortality, HWA population level, crown ratings and percent new growth.

[1]Submitted as a paper at the hemlock woolly adelgid symposium held in East Brunswick, New Jersey,

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Materials And Methods

Study Plots

Thirteen study plots were set up during the years 1988 to 1990, eleven of which were established in 1988. These plots were chosen as representative of natural hemlock stands and adelgid populations. Of the eleven, nine plots were infested with varying levels of hemlock woolly adelgid and two were uninfested. The same eleven plots were monitored in 1989. Two of the plots were abandoned in 1990 because they were continually being treated with chemicals and/or fertilized and field personnel were unable to get an accurate record of the treatments. In 1990 two plots were added, which left eleven plots that have been continuously monitored since 1990. Data was not available from one plot in 1998 because permission to enter the property could not be obtained from the new property owners. Permission was obtained in 1999.

After a plot was chosen as representative of a noninfested, lightly infested, or heavily infested hemlock stand, three subplots were established within each plot to ensure that an undisturbed group of trees could be observed from year to year. Subplots were set up using the following criteria: 1) located in the densest parts of the hemlock stands; 2) good accessibility to branches; 3) open areas of a plot were avoided because they were not representative of a plot as a whole.

A #10 prism was used to delineate the sample hemlock trees within the subplot. One tree was designated as the center tree and any tree that was observed within the 360-degree radius of the prism was included in the subplot. The tree lying closest to magnetic North with respect to the center tree was designated tree number 1. All hemlock trees within the prism, moving in a clockwise direction, were numbered sequentially.

New Growth - Foliage

New growth counts were recorded annually using the trees in the three subplots to determine the quality and health of the trees at each site. New growth comes out of the ends of the old branches, with the new growth readily distinguishable from the previous year's growth by the light green color of the new needles and lighter colored stem. These counts were completed from June to August. The procedure was as follows: a branch on a tree was chosen skewed toward the branches showing the most potential for new growth. A thirty-centimeter ruler was used to measure one foot of branch starting from the tip and proceeding toward the trunk. All the terminal ends of the shoots, both living and dead, were counted. The number of terminals with new growth was determined and the percent of new growth was calculated by dividing the total number of terminals into the total number with new growth. Ten samples were taken from each subplot, a total of thirty samples per plot. As many different trees were used as possible but if the branches could not be reached or if there were less than 10 trees in the subplot, more than one count was made per tree. If the branches on the subplot trees were inaccessible, counts were made from samples on trees as close as possible to the subplot.

HWA Population Levels

Previous work (Ward, 1991) indicated that the percent new growth in hemlocks declines precipitously when a population of 25 - 30 HWA per 100 needles is reached. There was no appreciable effect on the percentage of new growth when populations of HWA were less than 25 - 30 HWA per 100 needles. The HWA population categories were then assigned as follows with H = heavy, > 30 adelgids per 100 needles; L = light, < 30 adelgids per 100 needles; N = none, no adelgids per 100 needles.

Population levels were determined by sampling HWA infested trees just outside of the subplots. Cuttings were made from six different trees within the plot (2 cuttings per subplot), but outside the boundaries of the subplots. These cuttings were brought back to the laboratory and ten, 100 needle sections, were randomly selected from each of the six cuttings. All adelgids present in the sections were counted and then an average was obtained for each of the plots.

Crown Rating

The US Forest Service crown ratings of ratio, transparency and density for all the plots were implemented in 1994 as in Millers, *et. al*. 1992 with the exception of die back and crown diameter. Die back was not included in the crown ratings because the project has been ongoing for some time and there was no way to evaluate that measurement since it is unknown what the crowns were like at the beginning of the project. Crown diameter was felt to be highly variable and thus was not included in the data. Crown ratio is the percentage of total tree height that supports living foliage. Crown density is the amount of foliage; branches *etc*. that block light visibility through the crown and is expressed as a percentage. Crown transparency is the amount of visible light going through the live portion of the crown.

Mortality

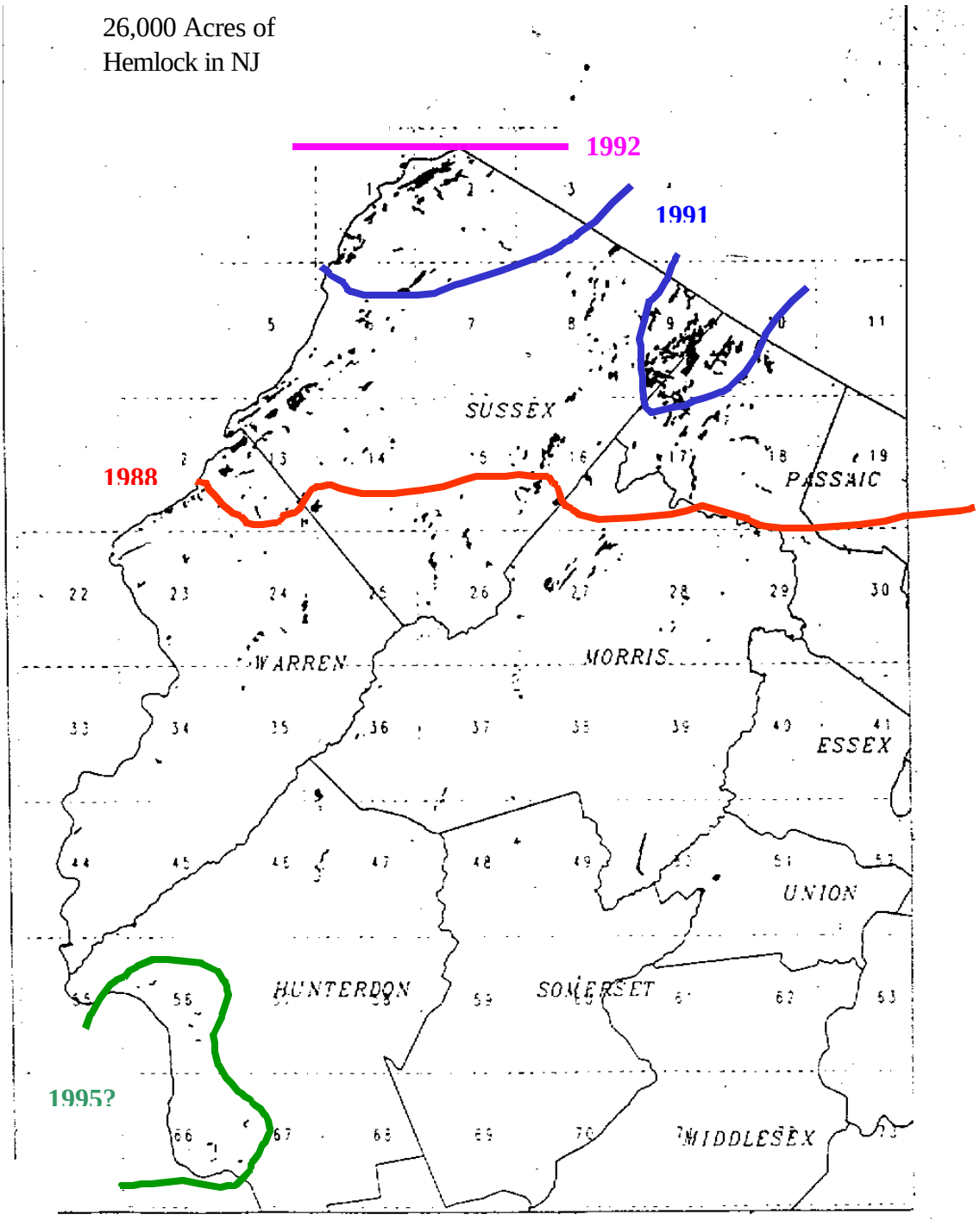
Counting the number of dead trees within the plot and calculating a percentage determined tree mortality. Mortality was defined as no cambial activity. No needles on the tree.

Statewide Hemlock Stand Survey

There are approximately 26,000 acres of eastern hemlock, *Tsuga canadensis* in New Jersey. All of the natural stands are in the northern part of the state. Figure 1 shows the location and the extent of the HWA population in NJ by year. NJ Department of Agriculture personnel did a survey of hemlock stands greater than 10 acres in size in the years 1988, 1992, 1997, and 2001. A total of 101 stands were surveyed in 1988, 111 in 1992, 159 in 1997 and 157 in 2001. The purpose of the survey was to delineate the hemlock woolly adelgid population in New Jersey and to get a relative idea of the tree health in the stands as well as to search for release/food collection sites for the coccinellid *Pseudoscymnus tsugae* Sasaji and McClure. In 2001, twenty trees were randomly sampled in each

stand and data was collected on crown transparency, crown ratio, adelgid population levels, slope, aspect and the presence of *Fiorinia* scale.

Figure 1. History of Infestation in NJ Hemlock Stands > 10 Acres in size



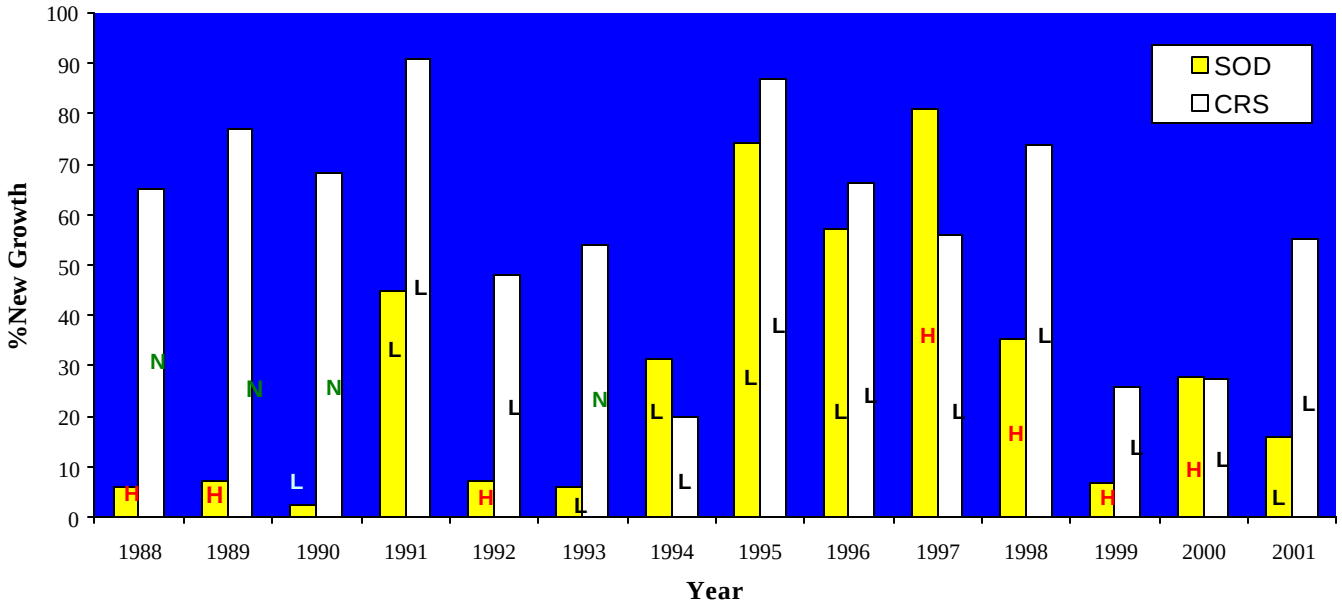
Results And Discussion

New Growth and HWA Population

Generally there is a series of years when the trees put out more new growth as long as the HWA population is light but as soon as the population becomes heavy, the amount of new growth declines except at the beginning of a heavy infestation. The trees become stressed and as the health of the tree declines less new growth is available and the HWA population declines. The trees are able to recover a bit and produce more new growth due to the lower HWA populations but after a year or two of recovery there is sufficient new growth for the HWA to come back at high population levels and stress the trees once again. This is expected since the HWA prefers new foliage and is rarely found on older material. After several years of heavy infestation the amount of new growth declines substantially (McClure, *et. al*. 1996).

Figure 2 shows the percent new growth and population level for two plots. The shades of Death (SOD) plot was heavily infested by the hemlock woolly adelgid in 1988 while the Clinton Reservoir (CRS) has had a light population of adelgid since 1991 but heavy populations have never developed there. The amount of new growth is much higher in the CRS plot than in the SOD plot, especially in the early nineties. SOD shows that the HWA population does decline and the trees do come back but they are reinfested and then decline again. Temperature is an important factor in the survival of the HWA. The January of 1994 was the coldest of the decade (Internet 1) and HWA populations were reduced by more than 90% in the SOD plot. The HWA They did not recover until 1997 when the population was high again and was high until 2000. Again this caused a decline in the amount of new growth with a corresponding decline in the health of the plot. There was no such decline in the CRS plot.

Figure 2. % New Growth at Shades of Death and Clinton Reservoir Plots 1988 - 2001



N = No hemlock woolly adelgid infestation.
H = Heavy hemlock woolly adelgid infestation.
L = Light hemlock woolly adelgid infestation.

Onken (1994) found that there was a relationship between the amount of rainfall that a stand received the previous year and the amount of new growth that a stand put out the following year. If the previous year was wet, then the trees put out a greater amount of new growth the following year. Therefore, weather and the amount of water available also affect the health of the tree.

Water seems to play a major role in the amount of new growth and the survivability of the trees. In the plots with high tree mortality field personnel have observed that the trees located at the bottom of a hill, at the edge of a road or near water have done substantially better with new growth and survivability. In our observations of infested stands, the surviving trees with access to the most water in the plots are the ones that generally are the healthiest, although the amount of foliage left on these surviving trees is still substantially less than what would be present in uninfested stands. Usually, the more xeric sites at the top of ridges and the sites where the hemlock is growing in marginal conditions are the sites where the heaviest mortality is found in NJ. Eventually, the trees do succumb.

Crown Ratings

Table 1 shows the population level of the HWA, and tree mortality in the plots over the course of the project while Figure 3 shows the crown transparency ratings for four of the plots from 1994 to 2001. The plots that have a series of years where the HWA population was heavy are the plots that have the

lowest crown ratios, lowest crown densities and the highest transparencies. Taken all together, the relative health of the hemlock in these plots (Shades of Death, Schooley's Mountain, Johnson Lake, or Lake Valhalla, Worthington State Forest, and Walnridge) is poor when compared to lightly infested stands (High Point, Tillman's Ravine, and Clinton Reservoir) where the trees are relatively unimpacted by the HWA. The stands that have been attacked earliest by the HWA are the stands that are in the poorest health in New Jersey.

Table 1. Percent New Growth, HWA Population Levels and Mortality in the New Jersey Permanent Plots 1988 - 2001.

Plot, % NG/Year	88	89	90	91	92	93	94	95	96	97	98	99	00	01
Hewitt SF	-	-	72	87	14	23	27	80	50	64	18	2	34	60
HWA Pop'n	L	L	L	L	L	L	L	L	L	H	H	H	H	L
% Mortality	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Clinton Res.	65	77	68	91	48	54	20	87	66	56	74	26	27	55
HWA Pop'n	N	N	N	L	L	N	L	L	L	L	L	L	L	L
% Mortality	0	0	0	0	0	0	0	0	0	3	3	3	14	35[1]
High Pt. SP	53	72	75	89	47	58	8	59	66	57	65	38	10	47
HWA Pop'n	N	N	N	L	L	L	N	L	L	L	L	H	H	L
% Mortality	0	0	0	0	3	9	9	12	12	12	15	15	23[2]	29[2]
Johnson Lake	58	42	7	9	1	12	8	69	59	58	34	4	22	63
HWA Pop'n	L	L	H	H	H	L	H	H	H	H	H	H	H	H
% Mortality	0	0	0	0	0	8	8	48	56	68	68	76	92	92
Lake Valhalla	65	74	51	47	0	28	30	78	35	41	40	7	17	50
HWA Pop'n	L	L	H	H	H	H	L	H	L	H	H	H	L	H
% Mortality	0	0	0	0	0	0	0	5	5	5	10	10	21	38
Millbrook	55	54	58	73	26	11	37	67	63	66	32	2	6	33
HWA Pop'n	L	L	L	H	H	H	N	L	L	L	H	H	L	L
% Mortality	0	0	0	0	5	5	5	5	5	5	5	5	5	5
Schooley's Mt.	6	4	6	59	25	44	24	80	55	50	-	14	25	55
HWA Pop'n	H	H	H	L	L	L	L	H	L	H	-	H	L	H
% Mortality	0	0	0	0	0	15	15	25	35	40	-	50	60	65
Shades of Death	6	7	2	45	7	6	32	74	57	81	35	7	28	48
HWA Pop'n	H	H	L	L	H	L	L	L	L	H	H	H	H	L
% Mortality	0	0	0	4	15	19	23	65	69	73	73	73	88	96
Tillman's Ravine	-	-	-	89	57	77	13	63	44	63	65	32	5	35
HWA Pop'n	-	-	-	N	L	N	N	N	N	L	L	L	H	L
% Mortality	-	-	-	0	0	0	0	0	0	5	5	5	5	5
Walnridge	75	51	20	-	21	46	60	40	31	82	72	6	33	75
HWA Pop'n	L	H	H	-	H	L	H	H	L	L	H	H	L	H
% Mortality	0	0	0	4	15	19	23	65	69	73	73	73	88	96
Worthington	7	12	13	53	0	25	21	64	58	80	72	6	13	28
HWA Pop'n	H	H	H	L	L	H	L	H	L	H	H	H	L	H
% Mortality	0	0	0	0	8	12	12	16	32	40	40	40	48	56

1Tree mortality is due to drought conditions and *Fiorinia externa* populations.

[2]Tree mortality is due to beaver damage and flooding in the plot rather than to the hemlock woolly adelgid.

Figure 3 shows that the trees do refoliate if given a respite from the HWA. The line for Worthington State Forest shows a decline in transparency from 1994 to 1996 and in 1999 which means that the tree

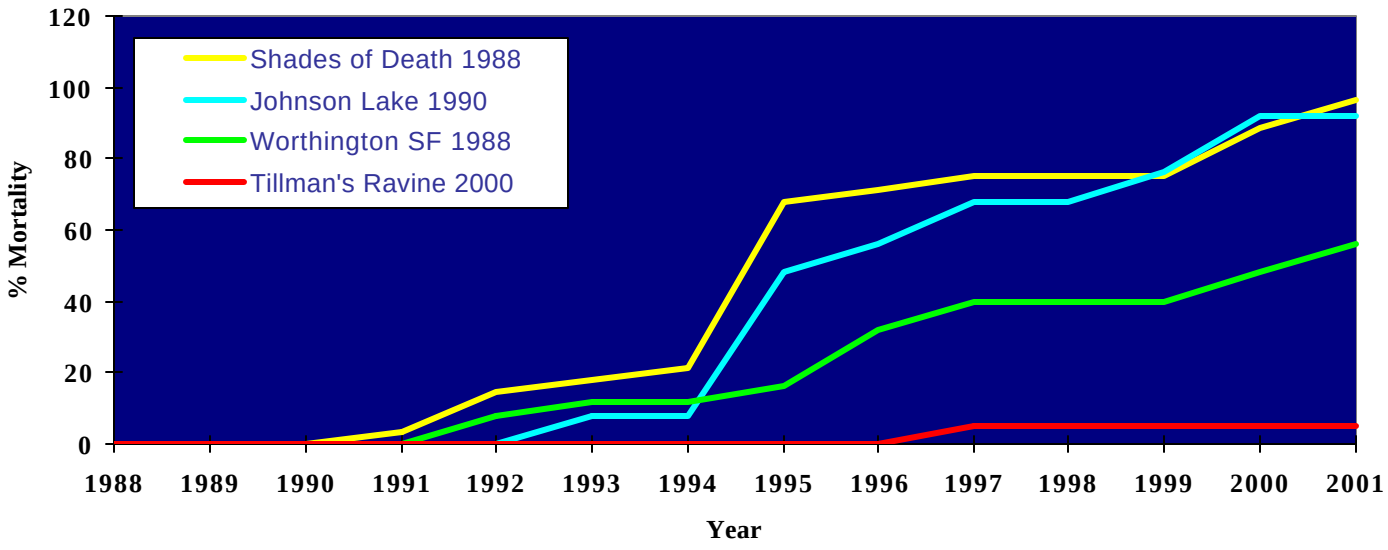
refoliated. These were years in which the HWA population had declined and or site conditions improved and the trees refoliated only to be defoliated again when the trees became heavily infested once again. Tillman's Ravine became heavily infested in 2000 and its transparency had already begun to increase due to the drought of 1999 but the transparency had substantially increased by 2001. For Tillman's Ravine, it may be the beginning of the end.

The most stressed trees have high crown ratings for transparency, the lower the number, the better off the tree is. As the HWA population in that stand increases, the crown ratings deteriorate. The effect is not seen for a few years but when the initial data from each stand is compared to the data from some years later the effect is readily apparent.

Tree Mortality Considerations

Obviously the HWA is putting stress on the trees in the forest. Figure 4 shows the stand mortality from 1988 to 2001 in four of the monitored stands. The years listed after the text in the legend

Figure 4. Cumulative Tree Mortality 1988 - 2001 in Four Plots



indicate the first year of heavy HWA infestation in a particular plot. The greatest mortality occurred in the stands that were heavily infested with the HWA for the longest period of time. These are also the stands that have the weakest crown ratings. The trend is disturbing in that where the HWA populations have been the heaviest; the tree mortality is the highest.

There is no hard and fast rule as to when substantial hemlock mortality may occur in an affected stand. In NJ, some tree mortality was observed five to six years after a heavy HWA infestation but it

increased substantially seven to eight years after the initial heavy HWA infestations. Twelve years after the initial infestations, tree mortality has reached over 90% in some hemlock stands and is increasing. Probably there are other factors that contribute to the death of the trees but the one factor that stands out consistently is the presence of a heavy HWA population. *Fiorinia externa* (Homoptera: Diaspididae) is present in many of the stands and is also a stressor but its overall effect on the stands is not clear. It appears to be a secondary pest. The hemlock borer, *Melanophila fulvoguttata* (Harris) (Coleoptera: Buprestidae) populations built up rapidly in the stressed stands and are the last indication that the stand is doomed. Hemlock mortality does seem to be somewhat affected by the amount of water available to the trees and the amount of water available is related to the percent new growth. At Shades of Death, Walnridge, Schooley's Mountain, Lake Valhalla and Johnson Lake, the trees that are still alive and last the longest are at the bottom of a slope, near a stream, or by a roadside which is at the bottom of a slope. It seems that if a site has been heavily infested, the trees that survive the longest are generally the ones that have the best access to a water supply but not always. Still, the trees eventually do die.

There is no concurrent mortality of other tree species in any of the stands. The HWA population declines as the trees become a poor food source; there is less new growth as the HWA population declines and the trees recover, but as the amount of new growth increases, the HWA population increases once again, starts a new cycle and the trees decline further.

When the trees do perish, they do not stay up long. Hemlock is a shallow-rooted tree with very brittle wood once it has died. Stands with extensive mortality have broken branches, broken crowns and dead logs littering the forest floor. It can be difficult, not to mention dangerous to walk through such a stand. Widowmakers (uprooted leaning trees) are a common sight and many of the trees have split and fallen. A municipal park with an extensive hemlock forest in Sparta, NJ has been closed because of the hazard that the dead hemlock trees represent. The hazard is even greater on windy days. High use public recreation areas with high hemlock mortality will be a threat to safety of the using public and will probably have to be closed or have the dead trees removed.

Statewide Stand Survey

The statewide stand survey was originally done in 1988 to get an idea of where the HWA was in New Jersey and to see what the stand health was like statewide. This was continued in 1992, 1997 and 2001. Table 2 shows the relationship between mortality and HWA population levels in 2001.

Table 2. Average Mortality in 2001 for Hemlock Stands in the New Jersey Statewide Survey in 1988, 1992, 1997 and 2001.

Infestation Level	Number times infested	Average Mortality
Heavy	3X	42.5%
Heavy	2X	32.4%
Heavy	1X	19.6%
Light, Never Heavy	1-3X	10.1%

None	0	4.1%

Only stands that were surveyed in at least three of the four years are included. Not all stands were surveyed in all four years, especially in 1988 and 1992. Some stands were inaccessible due to topography; weather or they were on military reservations. The relationship between mortality and the number of times that a stand has been heavily infested is quite evident. The stands that were heavily infested in three out of the four surveys had an average mortality of 42.5%; stands that were heavily infested two out of the four years had an average mortality of 32.4%; one out of four years 19.6%; stands that were only lightly infested and never heavily infested had an average mortality of 10.1% and if the stand was never infested, the average mortality was 4.1%. The more times that a stand was heavily infested, the greater the tree mortality.

Figure 5 shows the relationship between average percent mortality and crown transparency by stand. The data show that as transparency increases in a hemlock stand, the mortality increases and that there is a threshold of about 60% where the mortality increases substantially. Rhea (personal communication) found if hemlocks were defoliated more than 50%, that was the point of no return and the trees would not recover. The transparency data shows something analogous to that in that stands with foliage transparencies over 60%, have substantially increasing mortality. In New Jersey, only 22.9% of all the stands have average crown transparencies < 50%; only 8.2% of the stands have crown transparencies < 40%. If one considers the stands with transparencies between 40-50% to be borderline as far as tree health, then that leaves about 15-20 hemlock stands in New Jersey that remain healthy out of the 157 stands surveyed. The outlook is grim.

Figure 5. New Jersey 2001 Statewide Survey
% Mortality and Crown Transparency by Stand

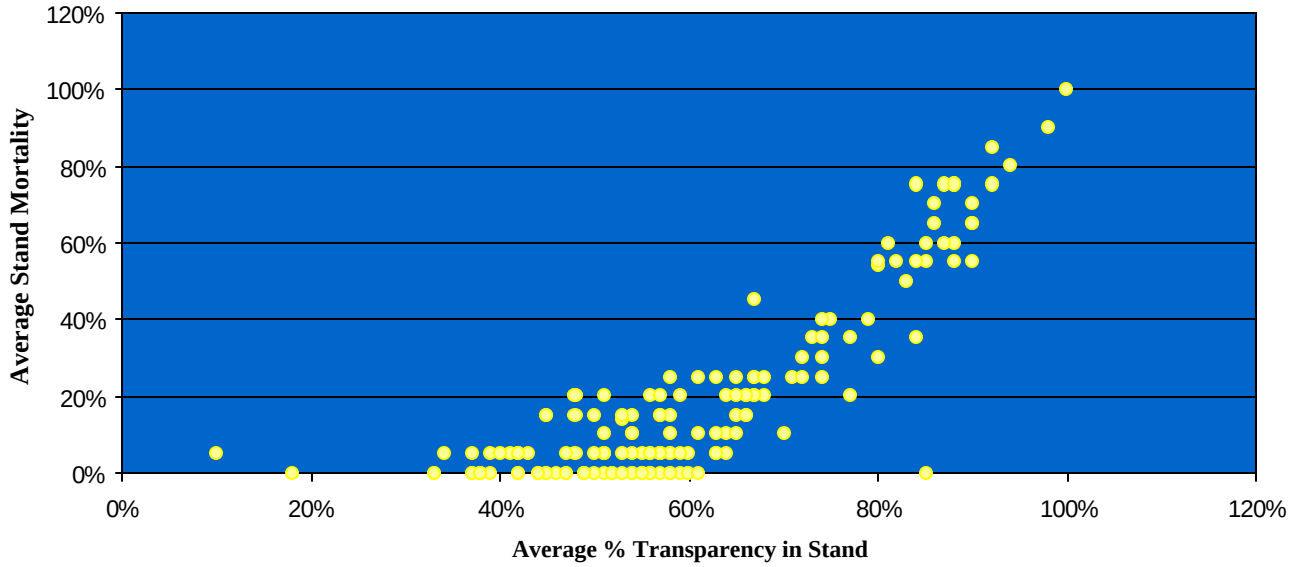
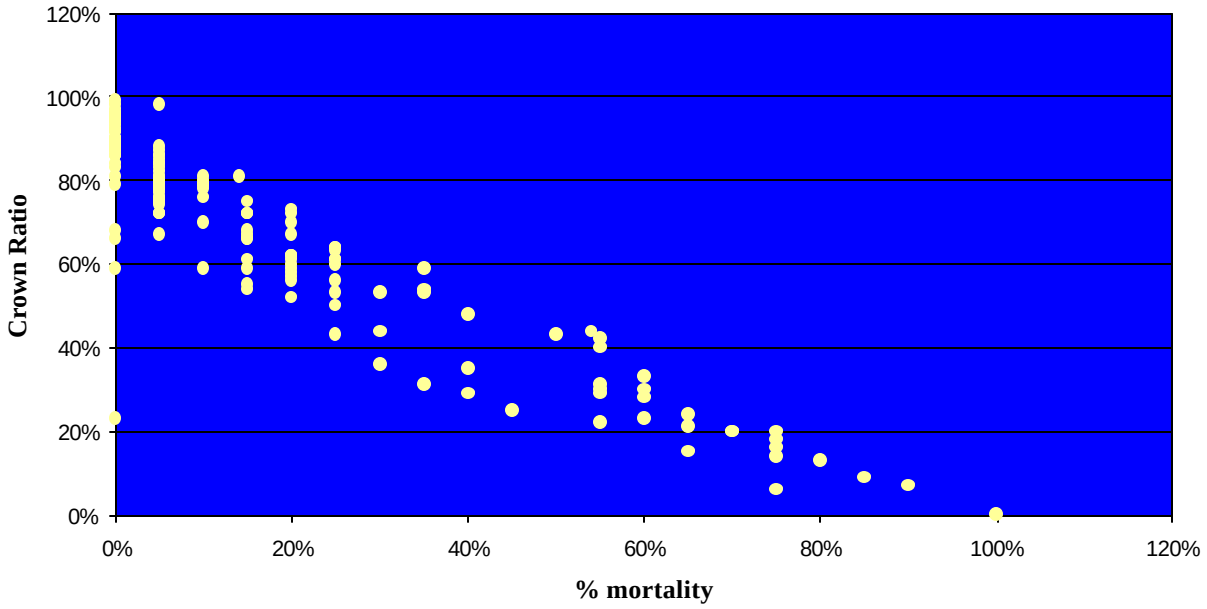


Figure 6 shows the relationship between crown ratio and mortality. Again, as with crown transparency, there is a linear relationship. As the crown ratio decreases, mortality increases but there does not seem to be a threshold as there was for the transparency. The trees gradually decline.

Figure 6. Average Crown Ratio and Mortality in 2001
NJ Statewide Survey



For forest managers, the USFS Crown Conditions Ratings would be very useful and quite inexpensive. Using the methods in Millers, *et. al*. 1992, a long term monitoring program could be set up that would be easy and accurate enough for foresters to make decisions about stands infested with the HWA.

Lastly, Figure 7 shows the devastation that the hemlock woolly adelgid can cause in forest stands. Two of the photos show Halsey Island in 1994 and 2001. In 1994, there were dead hemlocks, in 2001, all of the trees had come down. The other photos show the damage on the ground caused by this insect, hemlock borer damage and a healthy hemlock stand.

Figure 7. Damage Caused By The Hemlock Woolly Adelgid.

Dead hemlocks at Halsey Island 1994
Photo: George Koeck

Halsey Island 2001, no hemlocks
Photo: George Koeck

Dead hemlocks and slash at Johnson Lake 1998
Photos: Lauren Bronhard

Hemlock borer damage
Photo: Lauren Bronhard

Healthy hemlocks

Conclusion

From the results presented here, it is clear that the HWA is negatively impacting hemlock stands in New Jersey and mortality in the most heavily infested stands is increasing. The longer a stand has been heavily infested, and the more times that a stand has been heavily infested, the greater the tree mortality. Tree mortality shows up 5-6 years after a stand has been heavily infested. The HWA population crashes and the remaining trees recover. The HWA then increases its population again, impacts the trees, and the mortality substantially increases. It has taken about ten to twelve years from the initial heavy infestations to see mortality of over 90% in certain hemlock stands in NJ. Other environmental factors are involved, but the one factor that is consistent across the stands where the mortality is the greatest is a heavy population of HWA. The USFS crown rating of transparency increased while the crown ratio decreased. At a threshold of 60% crown transparency, the tree mortality in the stands increased significantly. Only 15 –20 hemlock stands out of the 157 surveyed in New Jersey are not seriously impacted by the hemlock woolly adelgid. Crown transparency could be a useful tool for forest managers because of its ease of use. The only remaining moderately impacted hemlock stands in New Jersey are primarily in the northwestern corner of the state.

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